

PRODUCTION OF ISOFLAVONE DERIVATIVES**Introduction**

5 The present invention relates to the hydrogenation of isoflavones and products thereof. The invention also relates to the synthesis of phytoestrogenic isoflavone metabolites and derivatives from the hydrogenation products of isoflavones.

Background of the Invention

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Isoflavone metabolites possess a very wide range of important biological properties including oestrogenic effects (WO 98/08503). Isoflavone metabolites can be isolated from the urine of human volunteers subjected to diets rich in plant isoflavonoids such as soya, lentils, peas and beans.

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In spite of the recently discovered biological significance of isoflavone metabolites there is not at present a general method suitable for the large scale synthesis of these metabolites. The few reported syntheses of these metabolites utilise either catalytic hydrogenation or hydrogen transfer reduction of the corresponding isoflavones. These reduction reactions are
20 found to be non-selective, extremely difficult to control and lead to mixtures of different products.

The reduction of 5,7-dihydroxyisoflavylium salts have been reported to give mixtures of isoflav-2-enes, isoflav-3-enes and isoflavans. The individual compounds are difficult to
25 separate and can be obtained only in low yields. Sodium borohydride reductions of isoflavones are known, see Ádám Major *et al. Liebigs Ann. Chem.* (1988) 555-558, however the reactions are low yielding, typically not clean and substituents on the basic isoflavone ring structure require tedious protective groups not affected by metal hydrides.

30 Chromatography is often required to separate the reaction products and only low yields of isoflavanones, isoflavan-4-ols, isoflavenes and isoflavans are obtained. The chromatography required is tedious and often impracticable for large scale reactions. Furthermore, attempts to improve the yield and purity of products obtained from

hydrogenation reactions has been met with limited success as evidenced by published results which are largely contradictory.

Solvents used in hydrogenation reactions of isoflavones reported in the literature include *N*-methylpyrrolidinone, see Liepa, A.J., *Aust. J. Chem.*, 1981, 34, 2647-55. However this solvent is unsuitable for pharmaceutical preparations of isoflavone metabolites and derivatives because *N*-methylpyrrolidinone is a severe eye irritant and a possible carcinogen. Furthermore the high boiling point of the solvent makes it extremely difficult to remove after the reduction.

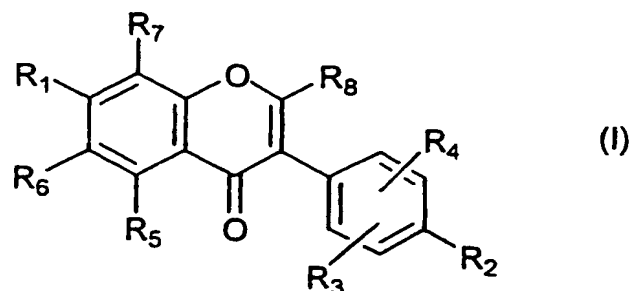
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Isoflavan-4-ols are key intermediates in the synthesis of isoflavones and accordingly there is a need for more efficient and reliable syntheses of isoflavan-4-ols, or at least comparable alternatives, acceptable than those known in the art. There is also a need for synthetic methods for isoflavone hydrogenation which utilise solvents pharmaceutically more acceptable than those previously reported. Therefore it is an object of the present invention to overcome or at least alleviate one or more of the above-mentioned disadvantages of the prior art. It is an other object of the present invention to synthesise novel isoflavone metabolites and derivatives.

20 Surprisingly hydrogenation conditions have been found by the present inventors which enable the synthesis of isoflavone derivatives in good to excellent yields. In particular the conditions found by the present inventors allow for the hydrogenation of isoflavones to relatively pure tetrahydroisoflavan-4-ol products in excellent yields, and without the need for pharmaceutically unsuitable solvents and extensive chromatography in the
25 hydrogenation reactions.

Summary of the Invention

Thus the present invention provides a method for the hydrogenation of a compound of
30 formula I

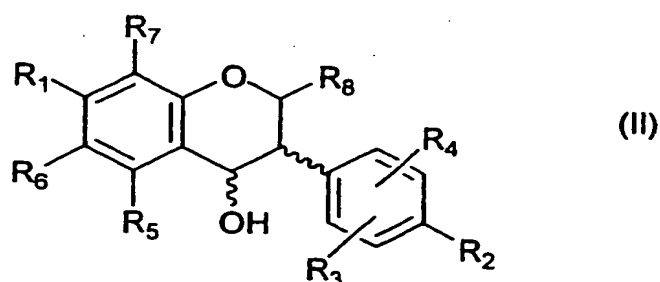


wherein

10 R_1 , R_2 , R_3 , R_4 , R_5 , R_6 , R_7 and R_8 are independently hydrogen, hydroxy, OR_9 , $OC(O)R_9$, $OS(O)R_9$, alkyl, haloalkyl, aryl, arylalkyl, thio, alkylthio, amino, alkylamino, dialkylamino, nitro or halo; and

R_9 is alkyl, haloalkyl, aryl, arylalkyl or alkylaryl,

to prepare a compound of formula II



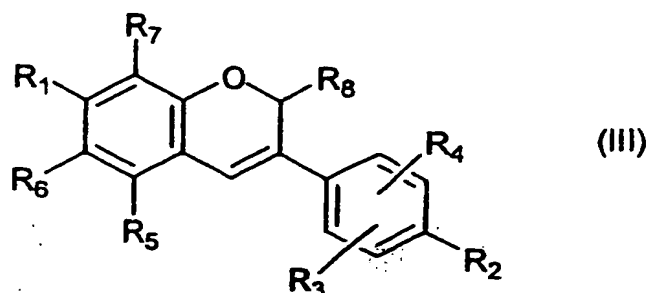
wherein

R_1 , R_2 , R_3 , R_4 , R_5 , R_6 , R_7 , R_8 and R_9 are as defined above.

25 The present invention also provides a method for the dehydration of a compound of formula II, which method may optionally include deprotection or transformation steps, to prepare a compound of the formula III

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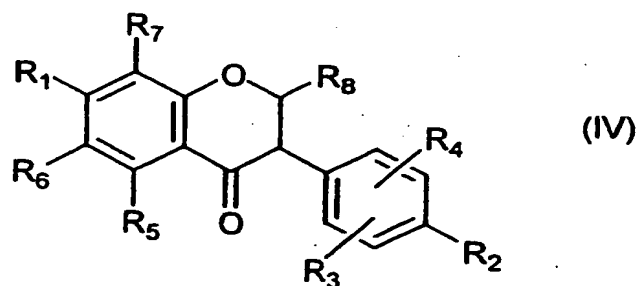
wherein

10 $R_1, R_2, R_3, R_4, R_5, R_6, R_7$ and R_8 are independently hydrogen, hydroxy, OR_9 , $OC(O)R_9$, $OS(O)R_9$, alkyl, haloalkyl, aryl, arylalkyl, thio, alkylthio, amino, alkylamino, dialkylamino, nitro or halo, and

R_9 is alkyl, haloalkyl, aryl, arylalkyl or alkylaryl.

15 The present invention also provides a method for the hydrogenation of a compound of formula I to prepare a compound of formula IV

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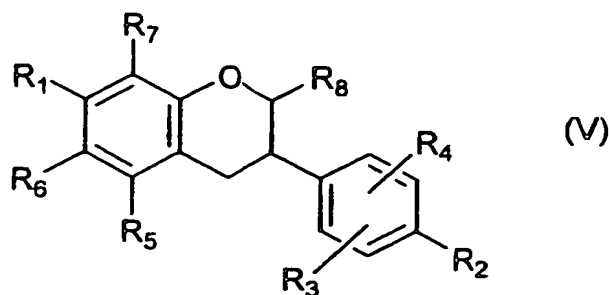


25 wherein

$R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8$ and R_9 are as defined above

The present invention also provides a method for the hydrogenation of a compound of formula III to prepare a compound of formula V

30



wherein

10 $R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8$ and R_9 are as defined above.

The present invention also provides compounds of formulae II, III, IV and V when prepared by a method described above and compositions comprising same.

15 The present invention also provides novel compounds of the formulae I, II, III, IV and V and compositions comprising same.

Detailed Description of the Invention

20 In the methods of the present invention, the starting isoflavone of formula I, the hydrogenation products isoflavan-4-ol of formula II, isoflavan-4-one of formula IV and isoflavan of formula V, and the dehydration product isoflav-3-ene of formula III preferably have the following substituents wherein

$R_1, R_2, R_3, R_4, R_5, R_6, R_7$ and R_8 are independently hydrogen, hydroxy, OR_9 , $OC(O)R_9$,
 25 $OS(O)R_9$, alkyl, aryl, arylalkyl, thio, alkylthio, bromo, chloro or fluoro, and
 R_9 is alkyl, fluoroalkyl or arylalkyl;

more preferably they have the following substituents wherein

R_1 is hydroxy, OR_9 or $OC(O)R_9$,

30 R_2, R_3, R_4, R_5, R_6 and R_7 are independently hydrogen, hydroxy, OR_9 , $OC(O)R_9$, alkyl, aryl or arylalkyl,

R_8 is hydrogen, and

R_9 is methyl, ethyl, propyl, isopropyl or trifluoromethyl; and

most preferably they have the following substituents wherein

R₁ is hydroxy, OR₉ or OC(O)R₉,

R₂, R₃, R₄, R₅ and R₇ are independently hydrogen, hydroxy, OR₉, OC(O)R₉, alkyl, aryl or
5 arylalkyl,

R₆ and R₈ are hydrogen, and

R₉ is methyl.

The particularly preferred compounds of formula I are 4',7-diacetoxyisoflavone (daidzein
10 diacetate) and 7-acetoxy-4'-methoxyisoflavone;

the particularly preferred compounds of formula II are 4',7-diacetoxyisoflavan-4-ol
(tetrahydrodaidzein diacetate) and 7-acetoxy-4'-methoxyisoflavan-4-ol;

the particularly preferred compounds of formula III are 4',7-diacetoxyisoflav-3-ene
(dehydroequol diacetate), 4',7-dihydroxyisoflav-3-ene (dehydroequol), 7-acetoxy-4'-
15 methoxyisoflav-3-ene and 7-hydroxy-4'-methoxyisoflav-3-ene;

the particularly preferred compounds of formula IV are 4',7-diacetoxyisoflavan-4-one
(diacetoxydihydrodaidzein) and 4',7-dihydroxyisoflavan-4-one (dihydrodaidzein); and

the particularly preferred compounds of formula V are 4',7-diacetoxyisoflavan (equol
diacetate) and 4',7-dihydroxyisoflavan (equol).

20

The novel compounds of the formulae I, II, III, IV and V preferably have the following
substituents wherein

R₁ is hydroxy, OR₉, OC(O)R₉, thio, alkylthio, or halo,

R₂, R₃, R₄, R₅, R₆, R₇ and R₈ are independently hydrogen, hydroxy, OR₉, OC(O)R₉,
25 OS(O)R₉, alkyl, aryl, thio, alkylthio or halo, and

R₉ is alkyl, fluoroalkyl or arylalkyl

with the proviso that

at least one of R₅, R₆ and R₇ is not hydrogen, or

when R₅, R₆ and R₇ are all hydrogen, then R₃ is hydroxy, OR₉, OC(O)R₉, OS(O)R₉, alkyl,
30 aryl, thio, alkylthio or halo; and

more preferably they have the following substituents wherein

R₁ is hydroxy, OR₉ or OC(O)R₉,

R₂ and R₃ are independently hydrogen, hydroxy, OR₉ or OC(O)R₉,

R₄, R₅, R₆, and R₈ are hydrogen,

R₇ is hydroxy, OR₉, OC(O)R₉, alkyl, aryl or halo, and

R₉ is methyl, ethyl, propyl, isopropyl, trifluoromethyl or benzyl; or

5 wherein

R₁ is hydroxy, OR₉, OC(O)R₉,

R₂ and R₃ are independently hydrogen, hydroxy, OR₉ or OC(O)R₉,

R₅ is OR₉, OC(O)R₉, alkyl, aryl or halo,

R₄, R₆, R₇, and R₈ are hydrogen, and

10 R₉ is methyl, ethyl, propyl, isopropyl, trifluoromethyl or benzyl.

Most preferably the novel compounds of formulae I, II and III are:

4',7,8-Triacetoxyisoflavone

7,8-Diacetoxy-4'-methoxyisoflavone

15 4',7-Diacetoxy-8-methylisoflavone

3',7-Diacetoxy-8-methylisoflavone

7-Acetoxy-4'-methoxy-8-methylisoflavone

4',7-Diacetoxy-3'-methoxy-8-methylisoflavone

4',5,7-Triacetoxyisoflavone

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4',7,8-Triacetoxyisoflavan-4-ol

7,8-Diacetoxy-4-methoxyisoflavan-4-ol

4',7-Diacetoxy-8-methylisoflavan-4-ol

3',7-Diacetoxy-8-methylisoflavan-4-ol

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7-Acetoxy-4'-methoxy-8-methylisoflavan-4-ol

4',7-Diacetoxy-3'-methoxy-8-methylisoflavan-4-ol

4',5,7-Triacetoxyisoflavan-4-ol

4',7,8-Trihydroxyisoflavan-4-ol

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7,8-Dihydroxy-4-methoxyisoflavan-4-ol

4',7-Dihydroxy-8-methylisoflavan-4-ol

3',7-Dihydroxy-8-methylisoflavan-4-ol

7-Hydroxy-4'-methoxy-8-methylisoflavan-4-ol

4',7-Dihydroxy-3'-methoxy-8-methylisoflavan-4-ol

4',5,7-Trihydroxyisoflavan-4-ol

4',7,8-Triacetoxydehydroequol (4',7,8-Triacetoxyisoflav-3-ene)

5 7,8-Diacetoxy-4-methoxydehydroequol (7,8-Diacetoxy-4-methoxyisoflav-3-ene)

4',7-Diacetoxy-8-methylisoflav-3-ene

3',7-Diacetoxy-8-methylisoflav-3-ene

7-Acetoxy-4'-methoxy-8-methylisoflav-3-ene

4',7-Diacetoxy-3'-methoxy-8-methylisoflav-3-ene

10 4',5,7-Triacetoxyisoflav-3-ene

Isoflav-3-ene-4',7,8-triol

4'-Methoxyisoflav-3-ene-7,8-diol

8-Methylisoflav-3-ene-4',7-diol

15 8-Methylisoflav-3-ene-3',7-diol

4'-Methoxy-8-methylisoflav-3-ene-7-ol

3'-Methoxy-8-methylisoflav-3-ene-4',7-diol

Isoflav-3-ene-4',5,7-triol

20 4',7-Dihydroxy-8-methylisoflavan-4-ol

7-Hydroxy-4'-methoxy-8-methylisoflavan-4-ol

The term "alkyl" is taken to mean both straight chain and branched chain alkyl groups such as methyl, ethyl, propyl, isopropyl, butyl, isobutyl, secbutyl, tertiary butyl, and the like.

25 Preferably the alkyl group is a lower alkyl of 1 to 6 carbon atoms. The alkyl group may optionally be substituted by one or more of fluorine, chlorine, bromine, iodine, carboxyl, C₁-C₄-alkoxycarbonyl, C₁-C₄-alkylamino-carbonyl, di-(C₁-C₄-alkyl)-amino-carbonyl, hydroxyl, C₁-C₄-alkoxy, formyloxy, C₁-C₄-alkyl-carbonyloxy, C₁-C₄-alkylthio, C₃-C₆-cylcoalkyl or phenyl.

30

The term "aryl" is taken to include phenyl and naphthyl and may be optionally substituted by one or more C₁-C₄-alkyl, hydroxy, C₁-C₄-alkoxy, carbonyl, C₁-C₄-alkoxycarbonyl, C₁-C₄-alkylcarbonyloxy or halo.

The term "halo" is taken to mean one or more halogen radicals selected from fluoro, chloro, bromo, iodo and mixtures thereof, preferably fluoro and chloro, more preferably fluoro. Reference to for example "haloalkyl" includes monohalogenated, dihalogenated and up to 5 perhalogenated alkyl groups. Preferred perhalogenated groups are trifluoromethyl and pentafluoroethyl.

The compounds of the invention include all salts, such as acid addition salts, anionic salts and zwitterionic salts, and in particular include pharmaceutically acceptable salts.

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Throughout this specification and the claims which follow, unless the context requires otherwise, the word "comprise", and variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integers or steps.

15

The hydrogenation is ideally preformed with hydrogen in the presence of a reduction catalyst and a solvent. The reaction is preferably conducted under hydrogen at a pressure of 1-20 atmospheres, more preferably 1-5 atmospheres. The reaction may be performed from 10 to 60°C and is typically carried out at room temperature.

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The reaction time may range from 12 hours to 96 hours or more and is typically about 55 hours or more. Generally better yields and cleaner reactions are achieved with longer reaction times. It will be appreciated that reaction conditions may be varied depending on the individual nature of the compounds and the progress of the hydrogenation reaction.

25

The reduction catalysts may be selected from heterogeneous catalysts (whereby the catalyst is insoluble in the reaction medium) or homogenous catalysts (whereby the catalyst is soluble in the reaction medium). Examples of heterogeneous reduction catalysts include Raney nickel, palladium black, palladium hydroxide on carbon, palladium on activated carbon (1% Pd to 30% Pd), palladium on alumina powder, palladium on various barium salts, sodium borohydride reduced nickel, platinum metal, platinum black, platinum on activated carbon (1% Pt to 10% Pt), platinum oxide, rhodium salts, ruthenium salts and their chiral salts and zinc oxide. Preferably the catalyst is palladium on activated carbon (1% Pd

to 10% Pd), more preferably about 5% palladium on carbon. Platinum oxide (Adam's catalyst) is also a very useful hydrogenation catalyst for the methods of the present invention to produce predominantly *cis*-isomers of isoflavan-4-ols.

5 Examples of homogeneous reduction catalysts include chlorotris (triphenylphosphine)rhodium, chloro(trisphenylphosphine)hydridoruthenium (II) and pentacyanocobaltate (II).

The solvents suitable for use in the present invention include but are not limited to C₁-C₈ 10 alcohols and polyols, alkyl acetates, tetrahydrofuran, ethers, dioxane and C₁-C₃ acids. Preferably the solvent is a C₁-C₆ alcohol or C₁-C₆ alkyl acetate, more preferably methanol, ethanol or ethyl acetate, as well as propanol, isopropanol, butanol, isobutanol, secbutanol, tertiary butanol, methyl formate, ethyl formate and methyl acetate. Most preferably the solvent is absolute methanol, ethanol or ethyl acetate.

15

The present inventors have found that with a judicious choice of catalysts, solvents and optionally protecting groups, isoflavones are reduced cleanly and in high yields to corresponding isoflavanols. In particular the use of absolute methanol or ethanol as a solvent provided for very clean catalytic hydrogenation over 5% palladium on charcoal of 20 isoflavones to afford up to quantitative yields of isoflavanols. In methods where, for example, 10% palladium on charcoal is employed, the reaction can proceed more rapidly, at times being complete within 12 hours. The ratio of *cis*- and *trans*-isomers of the isoflavan-4-ol hydrogenation product can vary with the choice of catalysts and the nature of the isoflavone substitute. By varying the methods of the present invention it is possible to 25 influence the isomeric ratio achieved during the reduction process.

Of particular interest are isoflavones with oxygen substitution (or precursors to oxygen substitution) at the 4'- and 7-positions as reduction of these compounds leads to the biologically important dehydroequol or precursors thereof. A convenient starting material is 30 daidzein which is readily obtained by established routes.

It will be understood that some moieties on the isoflavone rings may require protection or derivatisation prior to being subjected to hydrogenation. For example it may be desirable to

protect free hydroxy moieties with groups such as an acetoxy group to assist in the solubility of the substituted isoflavones and/or their susceptibility to hydrogenation. Protecting groups can be carried out by well established methods known in the art, for example as described in *Protective Groups in Organic Synthesis*, T. W. Greene.

5

In particular the present inventors have found it is useful to protect hydroxy groups when present as esters or ethers prior to reduction, with acetoxy or methoxy groups most favoured. Acylation is preferably carried out with the hydroxy compounds in a solvent mixture of a carboxylic acid anhydride and base. Protecting free hydroxy groups prior to hydrogenation increases yields up to and including quantitative yields. The reaction products are generally cleaner and do not require a chromatography step in the purification and isolation of the hydrogenation products.

Thus surprisingly, tetrahydrodaidzein diacetate was obtained in quantitative yield when the catalytic hydrogenation of diacetoxylaiddzein in ethanol was continued for 55 h. Spectroscopic analysis established the product to be a 1:1 mixture of *cis*- and *trans*-isomers. Pleasingly, no further reduction of tetrahydrodaidzein was observed even if the reduction was continued for longer periods of time.

20 In a similar manner it was also surprisingly found that the protected isoflavone 7-acetoxy-4'-methoxydaidzein smoothly and cleanly underwent hydrogenation in ethanol to afford a quantitative yield of a 1:1 mixture of *cis*- and *trans*-isomers of 7-acetoxy-4'-methoxyisoflavan-4-ol. This reaction appears to be quite general and was repeated on many different substrates in amounts of up to one half gram and more.

25

In this regard the inventors have found conditions which allow for the large scale generation of clean and near quantitative yields of isoflavan-4-ols compounds by hydrogenation of corresponding isoflavones. In particular, it has been found that kilogram quantities of diacetoxylaiddzein undergo smooth and efficient reduction to the isomeric *cis*- and *trans*- 4',7-diacetoxisoflavan-4-ols. The isomeric ratios can be influenced by the percentage of palladium in the catalyst.

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The *cis*-/*trans*-isomeric mixtures are able to be dehydrated to isoflav-3-enes without the need for separation. However, is desired, the mixtures are able to be separated by a variety of methods as set out below.

5 The mixture of *cis*- and *trans*-tetrahydrodaidzein compounds are able to be separated by preparative HPLC. This mode of separation is quite tedious and limited to small amounts of material. Since reasonable quantities of the diacetoxy isoflavanols were able to be prepared, fractional crystallisation was attempted to separate the *cis*- and *trans*-isomers. A single recrystallisation of the 1:1 mixture from ethanol gave predominantly *trans*-
10 diacetoxytetrahydrodaidzein (50% yield: 73% purity) (*cis*-isomer 27%). Subsequent recrystallisations from ethanol afforded the pure *trans*- isomer in 25% overall yield.

Likewise the 7-acetoxy-4'-methoxyisoflavan-4-ol was able to be fractionally recrystallised to give the pure *trans*-isomer, with the filtrate containing increased proportions of the *cis*-
15 isomer.

Most hydrogenations yielded 1:1 mixtures of *cis*- and *trans*-isoflavan-4-ols. However one derivative of note was 7-hydroxy-4'-methoxy-8-methylisoflavone, the hydrogenation of which afforded predominantly the *trans*- isomer in excellent yield.

20 Synthesis of tetrahydrodaidzein and related derivatives was achieved by removal of the protecting acetoxy groups under mild conditions, preferably with imidazole in ethanol at reflux. Tetrahydrodaidzein was isolated in 80% yield after crystallisation from aqueous ethanol.

25 Dehydration of isoflavan-4-ols leads to the unsaturated isoflav-3-enes. Thus reaction of a *cis*-/*trans*-mixture of isoflavan-4-ols with benzoyl chloride/dimethylformamide at 100°C has been reported in the literature by Liepa to give the desired isoflav-3-ene dehydration product. However this reaction could only be repeated in low yield. Dehydration may also
30 be effected by treatment with acids such as sulfuric acid, hydrochloric acid, polyphosphoric acid, thionyl chloride and the like. Alternative methods of dehydration using *p*-toluenesulfonic acid or trifluoroacetic acid in refluxing dichloromethane were also investigated, but these methods also afforded the isoflavenes in low yields.

Generally the present inventors found the dehydration reagent of choice to be phosphorus pentoxide in dichloromethane, which can yield isoflavenes in yields of greater than 60%. The dehydration reactions can be carried out on the hydrogenation products directly, or 5 deprotected derivatives thereof.

Synthesis of dehydroequol was achieved by removal of the protecting acetoxy groups under mild conditions as described for the synthesis of tetrahydrodaidzein, and dehydroequol was purified by standard crystallisation solvent mixtures such as ethanol/water. Other isoflav-3- 10 ene derivatives may be prepared by similar methods.

Hydrogen reduction of 4',7-diacetoxyl daidzein with Adam's catalyst (platinum(IV)-oxide) in ethyl acetate under an atmosphere of hydrogen afforded 4',7-diacetoxytetrahydrodaidzein. However unlike the palladium-on-charcoal reduction in ethanol, reductions with Adam's 15 catalyst gave predominantly the *cis*-isomer of 4',7-diacetoxytetrahydrodaidzein.

In another embodiment of the invention, hydrogenation of 4',7-diacetoxy daidzein with 5% palladium-on-charcoal in ethyl acetate as solvent under an atmosphere of hydrogen gave 4',7-diacetoxyl dihydrodaidzein in excellent yield (80%). These conditions provide access to 20 isoflavan-4-ones from the corresponding isoflavones in good to excellent yields.

Access to isoflavan derivatives such as equol is possible by hydrogenation of isoflav-3-enes with, preferably, palladium-on-charcoal in an alkyl acetate solvent under an atmosphere of hydrogen. Excellent yields of 75% and more of the hydrogenated products are obtainable by 25 these methods. The products are clean and are readily recrystallised.

The surprising results obtained by the present inventors are in sharp contrast to those reported in the literature for other attempted hydrogenations of isoflavones. One such marked advantage is the use of alkyl acetates or alcohol solvents such as absolute methanol 30 or ethanol in the hydrogenation reactions. The isoflavanols prepared by the methods of the present invention are typically very crystalline and can be isolated in good purity, and without the need for chromatography. The isoflavanols can be converted to isoflav-3-enes by dehydration. Further deprotection or derivatisation steps can be employed by those

skilled in the art to obtain natural isoflavan-4-ones, isoflavans, isoflavenes, metabolites and novel derivatives thereof as required.

The invention is further described in and illustrated by the following Examples. The 5 Examples are not to be construed as limiting the invention in any way.

EXAMPLES

Acetylation Reactions

10

Example 1

4',7-Diacetoxylaiddzein

Method A

A mixture of daidzein (1.0g, 3.9 mmol), acetic anhydride (5 ml) and pyridine (5 ml) was left 15 in the dark at room temperature for 24 h. The reaction mixture was poured into water (100 ml), stirred for 2h and then extracted with dichloromethane (3 x 50 ml). The dichloromethane layer was washed with water, dried over anhydrous sodium sulfate and evaporated. The white residue was crystallised from methanol to yield daidzein diacetate as white prisms (1.1 g, 83%). ¹H NMR (CDCl₃): δ 2.32 (s, 3H, OCOCH₃), 2.36 (s, 3H, 20 OCOCH₃), 7.18 (d, 2H, J 9.2 Hz, ArH), 7.19 (d, 1H, J 9.0 Hz, H6), 7.31 (d, 1H, J 2.0 Hz H8), 7.59 (d, 2H, J 9.2 Hz, ArH), 8.00 (s, 1H, H2), 8.33 (d, 2H, J 8.2 Hz, ArH).

Method B

A mixture of daidzein (2.0 g, 7.9 mmol), acetic anhydride (10 ml) and pyridine (2 ml) was 25 heated on an oil bath at 105-110 C for 1h. After cooling the mixture to room temperature, it was stirred for a further 30 min during which time the diacetate crystallised from the solution. The product was filtered, washed thoroughly with water and recrystallised from methanol to yield daidzein diacetate as colourless prisms (2.4 g, 90%).

30 Example 2

7-acetoxy-4'-methoxyisoflavone

A mixture of 7-hydroxy-4'-methoxyisoflavanone (2.0g, 7.5 mmol), acetic anhydride (10 ml) and pyridine (2 ml) was heated on an oil bath at 105-110 C for 1 hour. After cooling the

mixture to room temperature, it was poured into water (100 ml), stirred for 2 hours and then extracted with dichloromethane (3 x 50 ml). The dichloromethane layer was washed with water, dried over anhydrous sodium sulfate and evaporated. The white residue was crystallised from methanol to yield 7-acetoxy-4'-methoxyisoflavone as colourless prisms 5 (2.1g, 91%). ¹H NMR (CDCl₃): δ 2.36 (s, 3H, OCOCH₃), 3.84 (s, 3H, OCH₃), 6.98 (d, 2H, J 8.7 Hz, ArH), 7.16 (dd, 1H, J 1.9 Hz 8.6 Hz, H₆), 7.30 (d, 1H, J 1.9 Hz H₈), 7.50 (d, 2H, J 8.7 Hz, ArH), 8.00 (s, 1H, H₂), 8.32 (d, 1H, J 8.6 Hz, H₅).

Example 3

10 3',7-Diacetoxyisoflavone

3',7-Diacetoxydaidzein was prepared from 3',7-dihydroxyisoflavone (0.98g, 3.9 mmol), acetic anhydride (6 ml) and pyridine (1.1 ml) as described for 4',7-diacetoxydaidzein. Yield: (1.0g, 77%) m.p. 152°C. ¹H NMR (CDCl₃): δ 2.31 and 2.36 (each s, 3H, OCOCH₃), 7.14 (m, 1H, ArH), 7.18 (dd, 1H, J 2.0 Hz 8.6 Hz, H₆), 7.31 (d, 1H, J 2.0 Hz H₈), 7.37-7.45 (m, 15 3H, ArH), 8.03 (s, 1H, H₂), 8.32 (d, 1H, J 8.6 Hz, H₅). Mass spectrum: m/z 338 (M, 8%); 296 (53); 254 (100); 253 (60).

Example 4

7-Acetoxy-3'-methoxyisoflavone

20 7-Acetoxy-3'-methoxyisoflavone was prepared from 7-hydroxy-3'-methoxyisoflavone (1.7g, 6.3 mmol), acetic anhydride (6 ml) and pyridine (1.0 ml) as described for 4',7-diacetoxydaidzein. Yield: (1.6g, 81%) m.p. 118°C. ¹H NMR (CDCl₃): δ 2.36 (s, 3H, OCOCH₃), 3.85 (s, 3H, OMe), 6.95 (dd, 1H, J 2.0 Hz 8.3 Hz, H₆), 6.70-7.40 (m, 5H, ArH), 8.01 (s, 1H, H₂), 8.32 (d, 1H, J 8.7 Hz, H₅).

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Example 5

4',7-Diacetoxy-3'-methoxyisoflavone

4',7-Diacetoxy-3'-methoxyisoflavone was prepared from 4',7-dihydroxy-3'-methoxyisoflavone (0.37g, 1.3 mmol), acetic anhydride (2.5 ml) and pyridine (0.4 ml) as 30 described for 4',7-diacetoxydaidzein. Yield: (0.36g, 75%) m.p. 197°C. ¹H NMR (CDCl₃): δ 2.33, 2.36 (each s, 3H, OCOCH₃), 3.88 (s, 3H, OMe), 7.06-7.17 (m, 2H, ArH), 7.19 (dd,

1H, J 2.3 Hz 9.0 Hz, ArH), 7.32 (dd, 2H, J 2.3 Hz 7.6 Hz, ArH), 8.03 (s, 1H, H2), 8.32 (d, 1H, J 8.6 Hz, H5).

Example 6

5 7-Acetoxyisoflavone

7-Acetoxyisoflavone was prepared from 7-hydroxyisoflavone (2.6g, 10.9 mmol), acetic anhydride (16 ml) and pyridine (3.0 ml) as described for 4',7-diacetoxylaiddzein. Yield: (2.5g, 82%) m.p. 133°C. ¹H NMR (CDCl₃): δ 2.36 (s, 3H, OCOCH₃), 7.18 (dd, 1H, J 2.2 Hz 8.6 Hz, H6), 7.31 (d, 1H, J 2.2 Hz H8), 7.39-7.57 (m, 5H, ArH), 8.00 (s, 1H, H2), 8.33 10 (d, 1H, J 8.6 Hz, H5). Mass spectrum: m/z 280 (M, 28%); 237 (98); 238 (57).

Example 7

4',7,8-Triacetoxyisoflavone

A mixture of 4',7,8-trihydroxyisoflavone (1.4g, 5.2 mmol), acetic anhydride (8.4 ml) and 15 pyridine (2 ml) was heated on an oil bath at 105-110°C for 1h. After cooling the mixture to room temperature, it was stirred for a further 30 min during which time the diacetate crystallised from the solution. The product was filtered, washed thoroughly with water and recrystallised from ethyl acetate to yield 4',7,8-triacetoxyisoflavone as colourless prisms (1.49g, 73%) m.p. 190-192°C. ¹H NMR (CDCl₃): δ 2.32, 2.36, 2.42 (each s, 3H, 20 OCOCH₃), 7.18 (d, 2H, J 8.6 Hz, ArH), 7.28 (d, 1H, J 8.9 Hz, H6), 7.56 (d, 2H, J 8.6 Hz H8), 7.98 (s, 1H, ArH), 8.18 (d, 1H, J 8.9 Hz, H5).

Example 8

7,8-Diacetoxy-4'-methoxyisoflavone

25 7,8-Diacetoxy-4'-methoxyisoflavone was prepared from 7,8-dihydroxy-4'-methoxyisoflavone (0.82g, 2.9 mmol), acetic anhydride (4.9 ml) and pyridine (0.9 ml) as described for 4',7,8-triacetoxyisoflavone. Yield: (0.9g, 85%) m.p. 165°C. ¹H NMR (CDCl₃): δ 2.36, 2.42 (each s, 3H, OCOCH₃), 3.84 (s, 3H, OCH₃), 6.98 (d, 2H, J 9.0 Hz, ArH), 7.25 (d, 1H, J 8.7 Hz, H6), 7.48 (d, 2H, J 9.0 Hz H8), 7.95 (s, 1H, H2), 8.20 (d, 1H, J 30 9.1 Hz, H5). Mass spectrum: m/z 368 (M, 20%); 326 (15); 312 (18); 284 (80).

Example 9

4',7-Diacetoxy-8-methylisoflavone

A mixture of 4',7-dihydroxy-8-methylisoflavone (2.9g, 10.8 mmol), acetic anhydride (18 ml) and pyridine (3 ml) was heated on an oil bath at 105-110°C for 1h. After cooling the mixture to room temperature, it was stirred for a further 30 min during which time the diacetate crystallised from the solution. The product was filtered, washed thoroughly with water and recrystallised from ethyl acetate to yield 4',7-diacetoxy-8-methylisoflavone as colourless prisms (3.2g, 84%). ¹H NMR (CDCl₃): δ 2.31 (s, 3H, CH₃), 2.32, 2.39 (each s, 3H, OCOCH₃), 7.13 (d, 1H, J 9.0 Hz, H6), 7.17 (d, 2H, J 8.7 Hz, ArH), 7.59 (d, 2H, J 8.7 Hz, ArH), 8.07 (s, 1H, H2), 8.19 (d, 1H, J 8.7 Hz, H5).

10

Example 10**3',7-Diacetoxy-8-methylisoflavone**

3',7-Diacetoxy-8-methylisoflavone was prepared from 3',7-dihydroxy-8-methylisoflavone (1.3g, 4.8 mmol), acetic anhydride (8 ml) and pyridine (1.5 ml) as described for 4',7-diacetoxy-8-methylisoflavone. Yield: (1.2g, 70%) m.p. 112°C. ¹H NMR (CDCl₃): δ 2.31 (s, 3H, CH₃), 2.32, 2.39 (each s, 3H, OCOCH₃), 7.13 (m, 2H, ArH), 7.37-7.45 (m, 3H, ArH), 8.1 (s, 1H, H2), 8.18 (d, 1H, J 8.7 Hz, H5). Mass spectrum: m/z 352 (M, 6%); 310 (35); 268 (100); 267 (60).

20 Example 11**7-Acetoxy-4'-methoxy-8-methylisoflavone**

7-Acetoxy-4'-methoxy-8-methylisoflavone was prepared from 7-hydroxy-4'-methoxy-8-methylisoflavanone (3.0g, 10.6 mmol), acetic anhydride (10 ml) and pyridine (2.0 ml) as described for 4',7-diacetoxy-8-methylisoflavone. Yield: (2.0g, 58%) m.p. 190-192°C. ¹H NMR (CDCl₃): δ 2.31 (s, 3H, CH₃), 2.38 (s, 3H, OCOCH₃), 3.84 (s, 3H, OMe), 6.98 (d, 2H, J 8.7 Hz, ArH), 7.12 (d, 1H, J 8.6 Hz, H6), 7.52 (d, 2H, J 8.7 Hz, ArH), 8.03 (s, 1H, H2), 8.18 (d, 1H, J 8.6 Hz, H5). Mass spectrum: 325 (M + 1, 13%); 324 (M, 58%); 282 (100); 281 (42).

30 Example 12**4',7-Diacetoxy-3'-methoxy-8-methylisoflavone**

4',7-Diacetoxy-3'-methoxy-8-methylisoflavone was prepared from 4',7-dihydroxy-3'-methoxy-8-methylisoflavone (0.42g, 1.4 mmol), acetic anhydride (2.6 ml) and pyridine (0.5 ml) as described for 4',7-diacetoxy-8-methylisoflavone. Yield: (0.4g, 74%) m.p. 209°C. ¹H NMR (CDCl₃): δ 2.22 (s, 3H, CH₃), 2.32, 2.39 (each s, 3H, OCOCH₃), 3.89 (s, 3H, OMe), 5 7.07-7.11 (m, 2H, ArH), 7.13 (d, 1H, J 8.6 Hz, H6), 7.32 (d, 1H, J 1.5 Hz, ArH), 8.09 (s, 1H, H2), 8.18 (d, 1H, J 8.7 Hz, H5).

Hydrogenation Reactions:- Isoflavone → Isoflavan-4-ol

10

Example 13

4',7-diacetoxytetrahydrodaidzein (4'-7-Diacetoxyisoflavan-4-ol)

Method A

Palladium-on-charcoal (5%, 0.08 g) was added to a suspension of 4',7-diacetoxydaidzein 15 (0.5 g, 1.5 mmol) in absolute ethanol (400 ml) and the mixture was stirred at room temperature under a hydrogen atmosphere for 55 hours. The catalyst was removed by filtration through Celite and the filtrate was evaporated *in vacuo* to yield 4',7-diacetoxytetrahydrodaidzein (0.51 g, 100%) in quantitative yield. A nuclear magnetic resonance spectrum revealed the product to be a clean 1:1 mixture of *cis*- and *trans*-4',7- 20 diacetoxytetrahydrodaidzein.

The *cis*- and *trans*-isomers were able to be separated by fractional recrystallisation. A 1:1 mixture of *cis*- and *trans*-4',7-diacetoxytetrahydrodaidzein (0.17 g), prepared as above, was dissolved in excess absolute ethanol and concentrated on a rotary evaporator. At the first 25 sign of crystallisation, further concentration of ethanol was stopped and the flask was cooled in an ice-bath. The resulting crystals were filtered and washed with a small amount of cold absolute ethanol. A nuclear magnetic resonance spectrum of the product (0.08 g) revealed it to be a mixture *trans*-4',7-diacetoxytetrahydrodaidzein (73%) and *cis*-4',7-diacetoxytetrahydrodaidzein (27%). Further recrystallisations of the mixture from ethanol 30 yielded the pure *trans*-4',7-diacetoxytetrahydrodaidzein (0.04 g, 24%).

• •

10 (C3), 68.04 (C2), 69.01 (C4), 109.67 (C8), 114.26 (C6), 121.96, 128.96 (ArCH), 129.40 (C5).

15 Hz, H2); 4.56 (dd, 1H, J 10.5 Hz, 11.8 Hz, H2), 4.75 (dd, 1H, J 1.3 Hz, 3.2 Hz, H4), 6.66 (dd, 1H, J 2.3 Hz, 8.7 Hz, H6), 6.69 (d, 1H, J 2.3 Hz, H8), 7.08 (d, 2H, J 8.6 Hz, ArH), 7.26 (d, 1H, 8.4 Hz, H5), 7.29 (d, 2H, J 8.6 Hz ArH). ¹³C NMR (CDCl₃); 20.98 (OCOCH₃), 43.52 (C3), 64.10 (C2), 66.46 (C4), 110.08 (C6), 114.09 (C8), 121.82, 129.40 (ArCH), 131.10 (C5).

20

Method B

25 Celite and the filtrate was evaporated *in vacuo* to yield 4',7-diacetoxytetrahydrodaidzein (29.5g, 96%). A nuclear magnetic resonance spectrum revealed the product to be a clean 2:1 mixture of *cis*- and *trans*-4',7-diacetoxytetrahydrodaidzein.

Method C

30 Palladium-on-charcoal (10%, 3.0 g) was added to a suspension of 4',7-diacetoxydaidzein (30.1g) in absolute methanol (3600 ml) and the mixture was stirred at room temperature under a hydrogen atmosphere for 15 hours. The catalyst was removed by filtration through Celite and the filtrate was evaporated *in vacuo* to yield 4',7-diacetoxytetrahydrodaidzein

(28.5g, 94%). A nuclear magnetic resonance spectrum revealed the product to be a clean 1:1 mixture of *cis*- and *trans*-4',7-diacetoxytetrahydrodaidzein.

Method D

5 Palladium-on-charcoal (5%, 100g) was added to a suspension of 4',7-diacetoxylaiddzein (980g) in absolute methanol (100L) and the mixture was stirred at room temperature under a hydrogen atmosphere for 78 hours. The catalyst was removed by filtration through a ceramic candle filtration apparatus and the filtrate was evaporated *in vacuo* to yield 4',7-diacetoxytetrahydrodaidzein (820g, 83%). A nuclear magnetic resonance spectrum revealed
10 the product to be a clean 2:1 mixture of *cis*- and *trans*-4',7-diacetoxytetrahydrodaidzein.

Example 14

Synthesis of 7-Acetoxy-4'-methoxyisoflavan-4-ol

Palladium-on-charcoal (5%, 0.08g) was added to a suspension of 7-acetoxy-4'-
15 methoxyisoflavone (0.5g, 1.6 mmol) in absolute ethanol (400 ml) and the mixture was stirred at room temperature under a hydrogen atmosphere for 55 hours. The catalyst was removed by filtration through Celite and the filtrate was evaporated *in vacuo* to yield 7-acetoxy-4'-methoxyisoflavan-4-ol (0.51g, 100%) in quantitative yield. A nuclear magnetic resonance spectrum revealed the product to be a clean 1:1 mixture of *cis*- and *trans*-7-
20 acetoxy-4'-methoxyisoflavan-4-ol.

The *cis*- and *trans*-isomers were able to be separated by fractional recrystallisation. A 1:1 mixture of *cis*- and *trans*-4',7-diacetoxytetrahydrodaidzein, prepared as above, was recrystallised three times from ethanol to yield pure *trans*-7-acetoxy-4'-methoxyisoflavan-4-
25 ol. The filtrate yielded predominantly *cis*-isomer.

For *trans*-7-Acetoxy-4'-methoxyisoflavan-4-ol; ¹H NMR (CDCl₃): δ 2.31 (s, 3H, OCOCH₃), 3.14 (dt, 1H, J 3.8 Hz, 8.6 Hz, H₃), 3.82 (s, 3H, OCH₃), 4.25 (dd, 1H, J 9.4 Hz, 11.3 Hz, H₂); 4.37 (dd, 1H, J 4.1 Hz, 11.3 Hz, H₂), 4.93 (d, 1H, J 7.8 Hz, H₄), 6.63 (d, 1H, J
30 2.3 Hz, H₈), 6.73 (dd, 1H, J 2.3 Hz, 8.3 Hz, H₆), 6.93 (d, 2H, J 8.7 Hz, ArH), 7.19 (d, 2H, J 8.7 Hz, ArH), 7.51 (d, 1H, J 7.9 Hz, H₅).

For *cis*-7-Acetoxy-4'-methoxyisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.30 (s, 3H, OCOCH_3), 3.28 (dt, 1H, J 3.4 Hz, J 12.1 Hz, H3), 3.84 (s, 3H, OCH_3), 4.36 (ddd, 1H, J 1.4 Hz, 3.8 Hz, 10.1 Hz, H2); 4.57 (dd, 1H, J 10.1 Hz, 11.3 Hz, H2), 4.75 (bs, 1H, H4), 6.58 (d, 1H, J 2.3 Hz, H8), 6.75 (dd, 1H, J 2.3 Hz, 8.3 Hz, H6), 6.96 (d, 2H, J 8.6 Hz, ArH), 7.25 (d, 2H, 8.6 Hz, ArH), 7.34 (d, 1H, J 8.3 Hz, H5).

Example 15

3'-7-Diacetoxyisoflavan-4-ol

Palladium-on-charcoal (5%, 0.03g) was added to a suspension of 3',7-diacetoxyisoflavanone 10 (0.2g, 0.6 mmol) in methanol (50 ml) and the mixture was stirred at room temperature under a hydrogen atmosphere for 55h. The catalyst was removed by filtration through Celite and the filtrate was evaporated *in vacuo* to yield 3'-7-diacetoxyisoflavan-4-ol in quantitative yield. A nuclear magnetic resonance spectrum revealed the product to be a clean 1 : 1 mixture of *cis*- and *trans*-3'-7-diacetoxyisoflavan-4-ol.

15

For *trans*-3'-7-diacetoxyisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.31 and 2.32 (each s, 3H, OCOCH_3), 3.17 (ddd, 1H, J 3.6 Hz, 8.6 Hz, 11.2 Hz, H3), 4.26 (dd, 1H, J 9.2 Hz, 11.6 Hz, H2); 4.33 (m, 1H, H2), 4.91 (d, 1H, J 7.9 Hz, H4), 6.60-6.73 (m, ArH), 6.97-7.16 (m, ArH), 7.25-7.48 (m, ArH).

20

For *cis*-3'-7-diacetoxyisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.30 and 2.31 (each s, 3H, OCOCH_3), 3.31 (dt, 1H, J 3.3 Hz, J 11.6 Hz, H3), 4.31 (m, 1H, H2); 4.57 (dd, 1H, J 10.6 Hz, 11.9 Hz, H2), 4.79 (bs, 1H, H4), 6.60-6.73 (m, ArH), 6.97-7.16 (m, ArH), 7.25-7.48 (m, ArH).

25

Example 16

7-Acetoxy-3'-methoxyisoflavan-4-ol

Cis- and *trans*-7-acetoxy-3'-methoxyisoflavan-4-ol was prepared from 7-acetoxy-3'-methoxyisoflavone (0.5g, 1.6 mmol) and palladium-on-charcoal (5%, 0.12g) in methanol 30 (100 ml) by the method described above.

For *trans*-7-acetoxy-3'-methoxyisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.28 (s, 3H, OCOCH_3), 3.15 (ddd, 1H, J 3.8 Hz, 8.3 Hz, 12.0 Hz, H3), 3.80 (s, 3H, OMe), 4.26 (dd, 1H, J 9.4 Hz, 11.3 Hz, H2); 4.32 (m, 1H, H2), 4.95 (d, 1H, J 7.9 Hz, H4), 6.60-6.93 (m, ArH), 7.23-7.33 (m, ArH), 7.49 (d, J 8.7 Hz, ArH).

5

For *cis*-7-acetoxy-3'-methoxyisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.28 (s, 3H, OCOCH_3), 3.30 (dt, 1H, J 3.3 Hz, J 11.7 Hz, H3), 4.31 (m, 1H, H2); 4.58 (dd, 1H, J 10.5 Hz, 11.7 Hz, H2), 4.81 (bs, 1H, H4), 6.60-6.93 (m, ArH), 7.23-7.33 (m, ArH), 7.49 (d, J 8.7 Hz, ArH).

10 Example 17

4',7-Diacetoxy-3'-methoxyisoflavan-4-ol

Cis- and *trans*-4'-7-diacetoxy-3'-methoxyisoflavan-4-ol was prepared from 4'-7-diacetoxy-3'-methoxyisoflavone (0.25g, 0.7 mmol) and palladium-on-charcoal (5%, 0.06g) in methanol (50 ml) by the method described above.

15

For *trans*-4'-7-diacetoxy-3'-methoxyisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.29, 2.31 (each s, 3H, OCOCH_3), 3.17 (ddd, 1H, J 3.8 Hz, 8.7 Hz, 12.5 Hz, H3), 3.79 (s, 3H, OMe), 4.26 (dd, 1H, J 9.4 Hz, 11.3 Hz, H2); 4.32 (m, 1H, H2), 4.93 (d, 1H, J 7.9 Hz, H4), 6.62-6.73 (m, ArH), 6.81-6.91 (m, ArH), 6.99-7.05 (m, ArH), 7.30 (d, J 8.3 Hz, ArH), 7.48 (d, J 9.0 Hz, 20 ArH).

For *cis*-7-acetoxy-3'-methoxyisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.31, 2.32 (each s, 3H, OCOCH_3), 3.33 (dt, 1H, J 3.3 Hz, J 11.3 Hz, H3), 3.83 (s, 3H, OMe), 4.31 (m, 1H, H2); 4.58 (t, 1H, J 10.5 Hz, H2), 4.82 (bs, 1H, H4), 6.62-6.73 (m, ArH), 6.81-6.91 (m, ArH), 25 6.99-7.05 (m, ArH), 7.30 (d, J 8.3 Hz, ArH), 7.48 (d, J 9.0 Hz, ArH).

Example 18

7-Acetoxyisoflavan-4-ol

Cis- and *trans*-7-acetoxyisoflavan-4-ol was prepared from 7-acetoxyisoflavone (0.4g, 1.4 30 mmol) and palladium-on-charcoal (5%, 0.09g) in absolute methanol (60 ml). m.p. 90°C. Mass spectrum: m/z 284 (M, 10%); 226 (42); 138 (100); 137 (58).

For *trans*-7-acetoxyisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.29 (s, 3H, OCOCH_3), 3.17 (m, 1H, H3), 4.27 (t, 1H, J 10.6 Hz, H2); 4.30 (m, 1H, H2), 4.97 (d, 1H, J 8.3 Hz, H4), 6.60-6.73 (m, ArH), 7.08 (d, J 8.7 Hz, ArH), 7.23-7.37 (m, ArH), 7.49 (d, J 8.7 Hz, ArH).

5 For *cis*-7-acetoxyisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.30 (s, 3H, OCOCH_3), 3.33 (dt, 1H, J 3.4 Hz, J 11.7 Hz, H3), 4.36 (m, 1H, H2); 4.62 (t, 1H, J 10.5 Hz, H2), 4.80 (bs, 1H, H4), 6.60-6.73 (m, ArH), 7.08 (d, J 8.7 Hz, ArH), 7.23-7.37 (m, ArH), 7.49 (d, J 8.7 Hz, ArH).

Example 19

10 4',7,8-Triacetoxyisoflavan-4-ol

Palladium-on-charcoal (5%, 0.07g) was added to a suspension of 4',7,8-triacetoxyisoflavone (0.5g, 1.3 mmol) in methanol (100 ml) and the mixture was stirred at room temperature under a hydrogen atmosphere for 55h. The catalyst was removed by filtration through Celite and the filtrate was evaporated *in vacuo* to yield 4',7,8-triacetoxyisoflavan-4-ol in 15 quantitative yield. A nuclear magnetic resonance spectrum revealed the product to be a clean 1:1 mixture of *cis*- and *trans*-4',7,8-triacetoxyisoflavan-4-ol. Mass spectrum: m/z 400 (M, 5%); 358 (12); 298 (12); 256 (24); 196 (20); 162 (70); 154 (100); 120 (80).

For *trans*-4',7,8-triacetoxyisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.28, 2.29, 2.31 (each s, 3H, 20 OCOCH_3), 3.20 (m, 1H, H3), 4.27 (dd, 1H, H2); 4.37 (m, 1H, H2), 4.93 (d, 1H, J 7.9 Hz, H4), 6.78 (d, 1H, J 8.3 Hz, H8), 7.09 (m, ArH), 7.11-7.31 (m, ArH), 7.39 (d, 1H, J 8.7 Hz, ArH).

For *cis*-4',7,8-triacetoxyisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.30, 2.31, 2.32 (each s, 3H, 25 OCOCH_3), 3.35 (m, 1H, H3), 4.38 (m, 1H, H2); 4.57 (t, 1H, J 10.6 Hz, H2), 4.75 (bs, 1H, H4), 6.78 (d, 1H, J 8.3 Hz, H8), 7.09 (m, ArH), 7.11-7.31 (m, ArH), 7.39 (d, 1H, J 8.7 Hz, ArH).

Example 20

30 7,8-Diacetoxy-4-methoxyisoflavan-4-ol

7,8-Diacetoxy-4-methoxyisoflavan-4-ol was prepared from 7,8-dihydroxy-4'-methoxyisoflavone (0.4g, 1.1 mmol) in methanol (120 ml) using palladium-on-charcoal (5%, 0.08g) by the method described above.

5 For *trans*-7,8-diacetoxy-4-methoxyisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.29, 2.30 (each s, 3H, OCOCH_3), 3.14 (ddd, 1H, J 3.9 Hz, 9.2 Hz, 12.5 Hz, H3), 3.79 (s, 3H, OCH_3), 4.24 (dd, 1H, J 9.6 Hz, 11.2 Hz, H2); 4.35 (m, 1H, H2), 4.92 (d, 1H, J 7.8 Hz, H4), 6.78 (d, 1H, J 8.6 Hz, H6), 6.90 (m, ArH), 7.13-7.22 (m, ArH), 7.38 (d, J 8.6 Hz, ArH).

10 For *cis*-7,8-diacetoxy-4-methoxyisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.30, 2.31 (each s, 3H, OCOCH_3), 3.29 (dt, 1H, J 3.0 Hz, J 12.0 Hz, H3), 3.80 (s, 3H, OCH_3), 4.36 (m, 1H, H2); 4.57 (t, 1H, J 10.6 Hz, H2), 4.75 (bs, 1H, H4), 6.77 (d, 1H, J 8.6 Hz, H6), 6.90 (m, ArH), 7.13-7.22 (m, ArH), 7.38 (d, J 8.6 Hz, ArH).

15 Example 21

4',7-Diacetoxy-8-methylisoflavan-4-ol

Palladium-on-charcoal (5%, 0.12g) was added to a suspension of 4',7-diacetoxy-8-methylisoflavone (1.0g, 2.8 mmol) in methanol (200 ml) and the mixture was stirred at room temperature under a hydrogen atmosphere for 55h. The catalyst was removed by filtration
20 through Celite and the filtrate was evaporated *in vacuo* to yield 4',7-diacetoxy-8-methylisoflavan-4-ol in quantitative yield, m.p. 135-37°C. A nuclear magnetic resonance spectrum revealed the product to be a clean 1:1 mixture of *cis*- and *trans*-4',7-diacetoxy-8-methylisoflavan-4-ol. Mass spectrum: 356 (M, 53%); 254 (86); 253 (100); 240 (80); 196 (37).

25

For *trans*-4',7-diacetoxy-8-methylisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.02 (s, 3H, CH_3), 2.30, 2.31 (each s, 3H, OCOCH_3), 3.15 (ddd, 1H, J 3.8 Hz, 8.6 Hz, 11.7 Hz, H3), 4.27 (dd, 1H, J 9.4 Hz, 11.3 Hz, H2); 4.39 (m, 1H, H2), 4.92 (d, 1H, J 7.5 Hz, H4), 6.64 (d, 1H, J 8.0 Hz, H6), 7.06-7.32 (m, ArH).

30

For *cis*-4',7-diacetoxy-8-methylisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.02 (s, 3H, CH_3), 2.31, 2.32 (each s, 3H, OCOCH_3), 3.28 (dt, 1H, J 3.4 Hz, J 11.7 Hz, H3), 4.40 (m, 1H, H2); 4.58

(dd, 1H, J 10.1 Hz, 11.7 Hz, H2), 4.78 (bs, 1H, H4), 6.67 (d, 1H, J 8.0 Hz, H6), 7.06-7.32 (m, ArH).

Example 22

5 3',7-Diacetoxy-8-methylisoflavan-4-ol

3',7-Diacetoxy-8-methylisoflavan-4-ol was prepared from 3',7-diacetoxy-8-methylisoflavone (0.25g, 0.7 mmol) in methanol (50 ml) using palladium-on-charcoal (5%, 0.06g) by the method described above.

10 For *trans*-3',7-diacetoxy-8-methylisoflavan-4-ol; ¹H NMR (CDCl₃): δ 2.03 (s, 3H, CH₃), 2.30, 2.32 (each s, 3H, OCOCH₃), 3.18 (ddd, 1H, J 3.8 Hz, 8.3 Hz, 12.1 Hz, H3), 4.28 (dd, 1H, J 9.0 Hz, 10.9 Hz, H2); 4.39 (m, 1H, H2), 4.94 (d, 1H, J 8.7 Hz, H4), 6.65 (d, 1H, J 7.9 Hz, H6), 6.98-7.39 (m, ArH).

15 For *cis*-3',7-diacetoxy-8-methylisoflavan-4-ol; ¹H NMR (CDCl₃): δ 2.05 (s, 3H, CH₃), 2.30, 2.32 (each s, 3H, OCOCH₃), 3.32 (dt, 1H, J 3.4 Hz, J 12.0 Hz, H3), 4.39 (m, 1H, H2); 4.59 (dd, 1H, J 10.5 Hz, 11.7 Hz, H2), 4.80 (bs, 1H, H4), 6.68 (d, 1H, J 8.3 Hz, H6), 6.98-7.39 (m, ArH).

20 Example 23

7-Acetoxy-4'-methoxy-8-methylisoflavan-4-ol

7-Acetoxy-4'-methoxy-8-methylisoflavan-4-ol was prepared from 7-hydroxy-4'-methoxy-8-methylisoflavone (0.25g, 0.8 mmol) in methanol (50 ml) using palladium-on-charcoal (5%, 0.08g) by the method described above. This hydrogenation reaction predominantly yielded 25 the *trans*-isomer.

For *trans*-7-Acetoxy-4'-methoxy-8-methylisoflavan-4-ol; ¹H NMR (CDCl₃): δ 2.02 (s, 3H, CH₃), 2.32 (s, 3H, OCOCH₃), 3.11 (ddd, 1H, J 3.8 Hz, 9.4 Hz, 12.1 Hz, H3), 3.80 (s, 3H, OMe), 4.25 (dd, 1H, J 9.4 Hz, 11.3 Hz, H2); 4.40 (dd, 1H, J 3.8 Hz, 12.6 Hz, H2), 4.92 (bd, 30 1H, H4), 6.67 (d, 1H, J 8.3 Hz, H6), 6.89 (d, 2H, J 8.7 Hz, ArH), 7.16 (d, 2H, J 8.7 Hz, ArH), 7.34 (d, 1H, J 8.3 Hz, H5).

Example 24**4',7-Diacetoxy-3'-methoxy-8-methylisoflavan-4-ol**

4',7-Diacetoxy-3'-methoxy-8-methylisoflavan-4-ol was prepared from 4',7-diacetoxy-3'-methoxy-8-methylisoflavone (0.25g, 0.7 mmol) in methanol (50 ml) using palladium-on-5 charcoal (5%, 0.07g) by the method described above.

For *trans*-4',7-diacetoxy-3'-methoxy-8-methylisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.05 (s, 3H, CH_3), 2.30, 2.32 (each s, 3H, OCOCH_3), 3.18 (ddd, 1H, J 3.8 Hz, 8.3 Hz, 11.4 Hz, H3), 3.79 (s, 3H, OMe), 4.28 (dd, 1H, J 9.0 Hz, 11.3 Hz, H2); 4.41 (m, 1H, H2), 4.93 (d, 1H, J 10 7.9 Hz, H4), 6.64 (d, 1H, J 7.9 Hz, H6), 6.75-6.92 (m, ArH), 7.00 (d, 1H, J 7.9 Hz, ArH), 7.16 (d, 1H, J 8.3 Hz, ArH).

For *cis*-3',7-diacetoxy-8-methylisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.05 (s, 3H, CH_3), 2.30, 2.32 (each s, 3H, OCOCH_3), 3.29 (dt, 1H, J 3.4 Hz, J 11.7 Hz, H3), 4.40 (m, 1H, H2); 4.59 15 (t, 1H, J 10.5 Hz, H2), 4.81 (bs, 1H, H4), 6.67 (d, 1H, J 7.9 Hz, H6), 6.75-6.92 (m, ArH), 7.03 (d, 1H, J 8.3 Hz, ArH), 7.33 (d, 1H, J 8.3 Hz, ArH).

Dehydration Reactions**20 Example 25****4',7-Diacetoxydehydroequol (4',7-Diacetoxyisoflav-3-ene)****Method A**

Distilled trifluoroacetic acid (0.1 ml) was added to a solution of *cis*- and *trans*-4',7-diacetoxytetrahydrodaidzein (0.1g) in dry distilled dichloromethane (15 ml) and the mixture 25 was refluxed under argon. Progress of the reaction was monitored by thin layer chromatography and further 0.1 ml portions of trifluoroacetic acid were added. After refluxing for 4 hours, the reaction mixture was cooled and washed successively with saturated sodium bicarbonate solution, water and brine. The resulting organic phase was dried, concentrated, chromatographed and crystallised to yield 4',7-diacetoxydehydroequol 30 as colourless prisms (0.034g, 35%). ^1H NMR ($\text{CDCl}_3 + d_6\text{-DMSO}$): δ 2.29 (s, 3H, OCOCH_3), 2.31 (s, 3H, OCOCH_3), 5.15 (s, 2H, H2), 6.62 (bs, 1H, H4), 6.65 (dd, 1H, J 2.1

Hz 8.2 Hz, H6), 6.75 (bs, 1H, H8), 7.06 (d, 1H, J 8.2 Hz H5), 7.12 (d, 2H, J 8.2 Hz, ArH), 7.43 (d, 2H, J 8.2 Hz, ArH).

Method B

5 *p*-Toluenesulfonic acid (0.02 g) was added to a solution of *cis*- and *trans*-4',7-diacetoxytetrahydrodaidzein (0.1 g) in dry distilled dichloromethane (15 ml) and the mixture was refluxed under argon. Progress of the reaction was monitored by thin layer chromatography and after 4h at reflux, the reaction mixture was passed through a short column of silica gel and the eluant recrystallised from ethanol to yield 4',7-
10 diacetoxymethoxyhydroquercetin as colourless prisms (0.025 g, 26%).

Method C

Phosphorous pentoxide (5g) was added with stirring to a solution of *cis*- and *trans*-4',7-diacetoxytetrahydrodaidzein (1.0g) in dry dichloromethane (80 ml). The mixture was stirred
15 at room temperature for 2 hours and filtered through a pad of Celite. The dichloromethane solution was concentrated and chromatographed on silica gel to yield 4',7-diacetoxymethoxyhydroquercetin as colourless prisms (0.64g, 67%).

Example 26

20 7-Acetoxy-4'-methoxyisoflav-3-ene

Phosphorus pentoxide (1.0g) was added with stirring to a solution of *cis*- and *trans*-7-acetoxy-4'-methoxyisoflavan-4-ol (0.1g, 0.3 mmol) in dry dichloromethane (20 ml). The mixture was stirred at room temperature for 2 hours and filtered through a pad of Celite. The organic phase was concentrated and chromatographed on silica gel to yield 7-acetoxy-
25 4'-methoxyisoflav-3-ene (0.04g, 42%). ¹H NMR (CDCl₃); δ 2.28 (s, 3H, OCOCH₃), 3.83 (s, 3H, OCH₃), 5.14 (s, 2H, H₂), 6.61 (dd, 1H, J 2.3 Hz 6.4 Hz, H₆), 6.65 (d, 1H, J 2.3 Hz, H₈), 6.69 (bs, 1H, H₄), 6.92 (d, 2H, J 9.0 Hz ArH), 7.04 (d, 1H, J 7.9 Hz, H₅), 7.37 (d, 2H, J 9.0 Hz, ArH).

30 Example 27

3',7-Diacetoxymethoxyhydroquercetin (3',7-Diacetoxymethoxyisoflav-3-ene)

3',7-Diacetoxymethoxyisoflav-3-ene was prepared from *cis*- and *trans*-3',7-diacetoxymethoxyisoflavan-4-ol (0.2g, 0.6 mmol) in dry dichloromethane (50 ml) using phosphorus pentoxide (2.0g). Yield:

(0.09g, 48%). ¹H NMR (CDCl₃): δ 2.29 and 2.32 (each s, 3H, OCOCH₃), 5.14 (s, 2H, H₂), 6.61 (d, 1H, J 2.3 Hz, H₈), 6.66 (dd, 1H, J 2.3 Hz 7.9 Hz, H₆), 6.79 (bs, 1H, H₄), 7.02-7.15 (m, 3H, ArH), 7.25-7.44 (m, 2H, ArH).

5 Example 28

7-Acetoxy-3'-methoxydehydroeiquol (7-Acetoxy-3'-methoxyisoflav-3-ene)

7-Acetoxy-3'-methoxyisoflav-3-ene was prepared from *cis*- and *trans*-7-acetoxy-3'-methoxyisoflavan-4-ol (0.25g, 0.8 mmol) in dry dichloromethane (20 ml) using phosphorus pentoxide (2.0g). Yield: (0.15g, 63%). ¹H NMR (CDCl₃): δ 2.28 (s, 3H, OCOCH₃), 3.85
10 (s, 3H, OMe), 5.15 (s, 2H, H₂), 6.60-6.67 (m, 2H, ArH), 6.78 (bs, 1H, H₄), 6.84-7.06 (m, 4H, ArH), 7.35 (t, 1H, J 8.6 Hz, ArH).

Example 29

4',7-Diacetoxy-3'-methoxyisoflav-3-ene

15 4',7-Diacetoxy-3'-methoxyisoflav-3-ene was prepared from *cis*- and *trans*-4',7-diacetoxy-3'-methoxyisoflavan-4-ol (0.20g, 0.5 mmol) in dry dichloromethane (20 ml) using phosphorus pentoxide (2.0g). Yield: (0.11g, 58%).

Example 30

20 7-Acetoxyisoflav-3-ene

7-acetoxyisoflav-3-ene was prepared from *cis*- and *trans*-7-acetoxyisoflavan-4-ol (0.4g, 1.4 mmol) in dry dichloromethane (60 ml) using phosphorus pentoxide (5.0g). Yield: (0.2g, 53%). ¹H NMR (CDCl₃): δ 2.29 (s, 3H, OCOCH₃), 5.18 (s, 2H, H₂), 6.61-6.67 (m, 2H, ArH), 6.79 (bs, 1H, H₄), 7.07 (d, 1H, J 7.9 Hz, H₅), 7.23-7.45 (m, 5H, ArH).

25

Example 31

4',7,8-Triacetoxydehydroeiquol (4',7,8-Triacetoxyisoflav-3-ene)

Phosphorus pentoxide (5.0g) was added with stirring to a solution of *cis*- and *trans*-4',7,8-triacetoxyisoflavan-4-ol (0.5g, 1.3 mmol) in dry dichloromethane (50 ml). The mixture was
30 stirred at room temperature for 2h and filtered through a pad of Celite. The resulting solution was concentrated and chromatographed on silica gel to yield 4',7,8-triacetoxyisoflav-3-ene (0.3g, 63%). ¹H NMR (CDCl₃): δ 2.29, 2.31, 2.32, (each s, 3H,

OCOCH₃), 5.15 (s, 2H, H₂), 6.72 (d, 1H, J 8.3 Hz, H₆), 6.75 (bs, 1H, H₄), 6.97 (d, 1H, J 7.9 Hz, H₅), 7.12 (d, 2H, J 8.7 Hz ArH), 7.41 (d, 2H, J 8.7 Hz, ArH).

Example 32

5 7,8-Diacetoxy-4-methoxydehydroequol (7,8-Diacetoxy-4-methoxyisoflav-3-ene)

7,8-Diacetoxy-4-methoxyisoflav-3-ene was prepared from *cis*- and *trans*-7,8-diacetoxy-4-methoxyisoflavan-4-ol (0.4g, 1.1 mmol) in dry dichloromethane (60 ml) using phosphorus pentoxide (5.0g). Yield: (0.18g, 47%). ¹H NMR (CDCl₃): δ 2.29, 2.32 (each s, 3H, OCOCH₃), 3.83 (s, 3H, OCH₃), 5.14 (s, 2H, H₂), 6.69 (bs, 1H, H₄), 6.71 (d, 1H, J 8.3 Hz, 10 H₆), 6.90 (d, 2H, J 8.6 Hz ArH), 6.95 (d, 1H, J 7.9 Hz, H₅), 7.36 (d, 2H, J 8.6 Hz, ArH).

Example 33

4',7-Diacetoxy-8-methylisoflav-3-ene

Phosphorus pentoxide (3.0g) was added with stirring to a solution of *cis*- and *trans*-4',7-15 diacetoxy-8-methylisoflavan-4-ol (0.55g, 1.5 mmol) in dry dichloromethane (25 ml). The mixture was stirred at room temperature for 2h and filtered through a pad of Celite. The resulting solution was concentrated and chromatographed on silica gel to yield 4',7-diacetoxy-8-methylisoflav-3-ene (0.25g, 48%). m.p. 140°C. ¹H NMR (CDCl₃): δ 2.04 (s, 3H, CH₃), 2.31, 2.32 (each s, 3H, OCOCH₃), 5.16 (s, 2H, H₂), 6.61 (d, 1H, J 8.3 Hz, H₆), 20 6.75 (bs, 1H, H₄), 6.94 (d, 1H, J 8.3 Hz, H₅), 7.13 (d, 2H, J 8.7 Hz, ArH), 7.45 (d, 2H, J 8.7 Hz, ArH). Mass spectrum: m/z 339 (M+1, 6%); 338 (M, 26); 296 (48); 254 (90); 253 (100).

Example 34

3',7-Diacetoxy-8-methylisoflav-3-ene

25 3',7-Diacetoxy-8-methylisoflav-3-ene was prepared from *cis*- and *trans*-3',7-diacetoxy-8-methylisoflavan-4-ol (0.25g, 0.7 mmol) in dry dichloromethane (20 ml) using phosphorus pentoxide (2.0g). Yield: (0.13g, 54%) m.p. 116°C. ¹H NMR (CDCl₃): δ 2.04 (s, 3H, CH₃), 2.31, 2.32 (each s, 3H, OCOCH₃), 5.16 (s, 2H, H₂), 6.61 (d, 1H, J 8.3 Hz, H₆), 6.79 (bs, 1H, H₄), 6.92 (d, 1H, J 8.3 Hz, ArH), 7.05 (dd, 1H, J 2.0 Hz, 8.0 Hz, ArH), 7.15 (s, 1H, ArH), 30 7.26 (d, 1H, J 8.0 Hz, ArH), 7.37 (t, 1H, J 8.0 Hz, ArH). Mass spectrum: m/z 339 (M+1, 15%); 338 (M, 22); 296 (54); 254 (30).

Example 35**7-Acetoxy-4'-methoxy-8-methylisoflav-3-ene**

7-Acetoxy-4'-methoxy-8-methylisoflav-3-ene was prepared from *cis*- and *trans*-7-acetoxy-4'-methoxy-8-methylisoflavan-4-ol (0.25g, 0.7 mmol) in dry dichloromethane (20 ml) using phosphorus pentoxide (2.0g). Yield: (0.11g, 46%) m.p. 107°C. ¹H NMR (CDCl₃): δ 2.04 (s, 3H, CH₃), 2.31 (s, 3H, OCOCH₃), 3.83 (s, 3H, OMe), 5.16 (s, 2H, H₂), 6.59 (d, 1H, J 8.3 Hz, H₆), 6.68 (bs, 1H, H₄), 6.90 (d, 1H, J 8.3 Hz, H₅), 6.93 (d, 2H, J 9.0 Hz, ArH), 7.37 (d, 2H, J 9.0 Hz, ArH). Mass spectrum: m/z 311 (M+1, 13%); 310 (M, 68); 267 (100); 152 (68); 135 (90).

10

Example 36**4',7-Diacetoxy-3'-methoxy-8-methylisoflav-3-ene**

4',7-Diacetoxy-3'-methoxy-8-methylisoflav-3-ene was prepared from *cis*- and *trans*-4',7-diacetoxy-3'-methoxy-8-methylisoflavan-4-ol (0.25g, 0.6 mmol) in dry dichloromethane (25 ml) using phosphorus pentoxide (2.0g). Yield: (0.14g, 58%) m.p. 123°C. ¹H NMR (CDCl₃): δ 2.05 (s, 3H, CH₃), 2.31. 2.32 (each s, 3H, OCOCH₃), 3.88 (s, 3H, OMe), 5.16 (s, 2H, H₂), 6.61 (d, 1H, J 8.3 Hz, H₆), 6.73 (bs, 1H, H₄), 6.94 (d, 1H, J 8.3 Hz, H₅), 6.97 (dd, 1H, J 1.9 Hz, 8.3 Hz, ArH), 7.03 (d, 1H, J 1.9 Hz, ArH), 7.05 (d, 1H, J 7.9 Hz, ArH).

20 **Deprotection Reactions****Example 37****Dehydroequol (Isoflav-3-ene-4',7-diol)**

Imidazole (0.09 g) was added to a suspension of 4',7-diacetoxydehydroequol (0.03 g, 0.09 mmol) in absolute ethanol (2.0 ml) and the mixture was refluxed for 45 min under argon. The solution was concentrated under reduced pressure and the product was precipitated by addition of distilled water (10 ml). The mixture was left overnight in the fridge and filtered to yield dehydroequol. The crude product was reprecipitated from methanol by addition of benzene to yield dehydroequol as fluffy white solid (0.012 g, 55%). ¹H NMR (CDCl₃ + d₆-DMSO): δ 4.93 (s, 2H, H₂), 6.26 (bs, 1H, H₄), 6.29 (dd, 1H, J 2.0 Hz, 8.2 Hz, H₆), 6.50 (bs, 1H, H₈), 6.73 (d, 2H, J 8.2 Hz, ArH), 6.76 (d, 2H, J 8.2 Hz, H₅), 7.13 (d, 2H, J 8.2 Hz, ArH).

Example 38**7-Hydroxy-4'-methoxyisoflav-3-ene**

Imidazole (0.18g) was added to a suspension of 7-acetoxy-4'-methoxyisoflav-3-ene (0.06g, 0.02 mmol) in absolute ethanol (5.0 ml) and the mixture was refluxed for 45 minutes under argon. The solution was concentrated under reduced pressure and the product was precipitated by addition of distilled water (10 ml). The mixture was left overnight in the fridge and filtered to yield isoflav-3-ene. The crude product was recrystallised from methanol/benzene to yield 7-hydroxy-4'-methoxyisoflav-3-ene (0.034g, 66%). ¹H NMR (CDCl₃ + d₆-DMSO): δ 3.74 (s, 3H, OCH₃), 4.99 (s, 2H, H₂), 6.21 (d, 1H, J 2.3 Hz, H₈), 6.29 (dd, 1H, J 2.3 Hz, 8.3 Hz, H₆), 6.67 (bs, 1H, H₄), 6.85 (d, 1H, J 8.3 Hz, H₅), 6.86 (d, 2H, J 8.7 Hz, ArH), 7.33 (d, 2H, J 8.7 Hz, ArH).

Example 39**15 Isoflav-3-ene-3',7-diol**

Isoflav-3-ene-3',7-diol was prepared from 3',7-diacetoxyisoflav-3-ene (0.09g, 0.3 mmol) and imidazole (0.3g) in ethanol (2.0 ml) as described for isoflav-3-ene-4',7-diol. Yield: (0.04g, 60%). ¹H NMR (CDCl₃ + d₆-DMSO): δ 4.94 (s, 2H, H₂), 6.21 (d, 1H, J 2.0 Hz, H₈), 6.29 (dd, 1H, J 2.3 Hz, 8.3 Hz, H₆), 6.62 (m, 1H, ArH), 6.64 (bs, 1H, H₄), 6.75-6.82 (m, 3H, ArH), 7.07 (t, 1H, J 7.9 Hz, ArH), 8.99-9.17 (bs, 2H, OH).

Example 40**3'-MethoxyIsoflav-3-ene-7-ol**

3'-MethoxyIsoflav-3-ene-7-ol was prepared from 7-acetoxy-3'-methoxyisoflav-3-ene (0.1g, 0.3 mmol) and imidazole (0.15g) in ethanol (2.0 ml) as described for isoflav-3-ene-4',7-diol. Yield: (0.06g, 70%) m.p. 75°C. ¹H NMR (CDCl₃): δ 3.84 (s, 3H, OMe), 5.12 (s, 2H, H₂), 6.38 (d, 1H, J 2.0 Hz, H₈), 6.40 (dd, 1H, J 2.0 Hz, 8.3 Hz, H₆), 6.76 (bs, 1H, H₄), 6.84 (dd, 1H, J 1.9 Hz, 8.3 Hz, ArH), 6.95 (m, 3H, ArH), 7.29 (t, 1H, J 8.3 Hz, ArH).

30 Example 41**3'-MethoxyIsoflav-3-ene-4',7-diol**

3'-Methoxyisoflav-3-ene-4',7-diol was prepared from 4',7-diacetoxy-3-methoxyisoflav-3-ene (0.11g, 0.3 mmol) and imidazole (0.3g) in ethanol (2.0 ml) as described for isoflav-3-ene-4',7-diol. Yield: (0.06g, 71%). ¹H NMR (d₆-acetone): δ 3.90 (s, 3H, OMe), 5.07 (s, 2H, H₂), 6.31 (d, 1H, J 2.3 Hz, H₈), 6.40 (dd, 1H, J 2.3 Hz, 8.3 Hz, H₆), 6.78 (bs, 1H, H₄), 6.83 (d, 1H, J 8.3 Hz, ArH), 6.92 (dd, 2H, J 1.9 Hz, 8.3 Hz, ArH), 7.14 (d, 1H, J 1.9 Hz, ArH), 7.04, 7.63 (each s, 1H, OH).

Example 42

Isoflav-3-ene-7-ol

10 Isoflav-3-ene-7-ol was prepared from 7-acetoxyisoflav-3-ene (0.2g, 0.75 mmol) and imidazole (0.24g) in ethanol (3.5 ml) as described for isoflav-3-ene-4',7-diol. Yield: (0.11g, 66%). m.p. 120°C. ¹H NMR (d₆-DMSO): δ 5.07 (s, 2H, H₂), 6.24 (d, 1H, J 2.2 Hz, H₈), 6.33 (dd, 1H, J 1.9 Hz, 7.9 Hz, H₆), 6.96 (d, 1H, J 7.9 Hz, H₅), 7.00 (s, 1H, H₄), 7.26-7.47 (m, 5H, ArH), 9.65 (bs, 1H, OH). Mass spectrum: m/z 224 (m, 74%); 223 (100), 175 (28); 15 165 (23); 147 (41).

Example 43

Isoflav-3-ene-4',7,8-triol

Imidazole (0.6g) was added to a suspension of 4',7,8-triacetoxyisoflav-3-ene (0.16g, 0.4 mmol) in absolute ethanol (5.0 ml) and the mixture was refluxed for 45 min under argon. The solution was concentrated under reduced pressure and the product was precipitated by addition of distilled water (10 ml). The mixture was left overnight in the fridge and filtered to yield isoflav-3-ene. The crude product was recrystallised from methanol/benzene to yield Isoflav-3-ene-4',7,8-triol (0.08g, 75%). ¹H NMR (CDCl₃ + d₆-DMSO): δ 4.97 (s, 2H, H₂), 25 6.30 (d, 1H, J 8.2 Hz, H₆), 6.36 (d, 1H, J 8.3 Hz, H₅), 6.55 (bs, 1H, H₄), 6.72 (d, 1H, J 8.7 Hz, ArH), 7.17 (d, 2H, J 8.7 Hz, ArH).

Example 44

4'-Methoxyisoflav-3-ene-7,8-diol

30 4'-Methoxyisoflav-3-ene-7,8-diol was prepared from 7,8-diacetoxy-4-methoxyisoflav-3-ene (0.15g, 0.4 mmol) and imidazole (0.4g) in ethanol (1.6 ml) as described for isoflav-3-ene-4',7,8-triol. Yield: (0.73g, 61%). ¹H NMR (CDCl₃ + d₆-DMSO): δ 3.83 (s, 3H, OCH₃),

5.15 (s, 2H, H2), 6.51 (d, 1H, J 8.3 Hz, H6), 6.58 (d, 1H, J 8.3 Hz, H5), 6.68 (bs, 1H, H4), 6.92 (d, 1H, J 8.7 Hz, ArH), 7.35 (d, 2H, J 8.7 Hz, ArH). Mass spectrum: m/z 270 (M, 5%); 256 (100); 255 (70); 239 (20); 181 (25).

5 Example 45

8-Methylisoflav-3-ene-4',7-diol

Imidazole (0.6g) was added to a suspension of 4',7-diacetoxy-8-methylisoflav-3-ene (0.25g, 0.7 mmol) in absolute ethanol (5.0 ml) and the mixture was refluxed for 45 min under argon.

The solution was concentrated under reduced pressure and the product was precipitated by 10 addition of distilled water (10 ml). The mixture was left overnight in the fridge and filtered to yield isoflav-3-ene. The crude product was recrystallised from methanol/benzene to yield 8-methylisoflav-3-ene-4',7-diol (0.13g, 68%). m.p. 190-93°C ¹H NMR (CDCl₃ + d₆-DMSO): δ 1.94 (s, 3H, CH₃), 4.98 (s, 2H, H2), 6.32 (d, 1H, J 7.9 Hz, H6), 6.58 (bs, 1H, H4), 6.67 (bd, 1H, H5), 6.72 (d, 2H, J 8.7 Hz, ArH), 7.21 (bd, 2H, ArH). Mass spectrum: 15 m/z 255 (M+1, 16%); 254 (M, 79); 253 (100); 161 (32).

Example 46

8-Methylisoflav-3-ene-3',7-diol

8-Methylisoflav-3-ene-3',7-diol was prepared from 3',7-diacetoxy-8-methylisoflav-3-ene 20 (0.12g, 0.4 mmol) and imidazole (0.3g) in ethanol (2.5 ml) as described for 8-methylisoflav-3-ene-4',7-diol. Yield: (0.07g, 77%) m.p. 130°C. ¹H NMR (CDCl₃ + d₆-DMSO): δ 1.95 (s, 3H, CH₃), 4.98 (s, 2H, H2), 6.34 (d, 1H, J 8.0 Hz, H6), 6.61-6.94 (m, 5H, ArH), 7.08 (bt, 1H, ArH). Mass spectrum: m/z 254 (M, 100%); 253 (96); 161 (45).

25 Example 47

4'-Methoxy-8-methylisoflav-3-ene-7-ol

4'-Methoxy-8-methylisoflav-3-ene-7-ol was prepared from 7-acetoxy-4'-methoxy-8-methylisoflav-3-ene (0.11g, 0.3 mmol) and imidazole (0.14g) in ethanol (1.5 ml) as described for 8-methylisoflav-3-ene-4',7-diol. Yield: (0.05g, 53%) m.p. 103°C. ¹H NMR 30 (d₆-acetone): δ 1.99 (s, 3H, CH₃), 3.81 (s, 3H, OMe), 5.11 (s, 2H, H2), 6.43 (d, 1H, J 8.3 Hz, H6), 6.77 (bs, 1H, H4), 6.80 (d, 1H, J 8.3 Hz, H5), 6.95 (d, 2H, J 9.0 Hz, ArH), 7.44 (d, 2H, J 9.0 Hz, ArH). Mass spectrum: 282 (M, 9%); 267 (100); 268 (95); 134 (52).

Example 48**3'-Methoxy-8-methylisoflav-3-ene-4',7-diol**

3'-Methoxy-8-methylisoflav-3-ene-4',7-diol was prepared from 4',7-diacetoxy-3'-methoxy-8-methylisoflav-3-ene (0.21g, 0.6 mmol) and imidazole (0.52g) in ethanol (4 ml) as described for 8-methylisoflav-3-ene-4',7-diol. Yield: (0.1g, 63%). ¹H NMR (CDCl₃): δ 2.14 (s, 3H, CH₃), 3.94 (s, 3H, OMe), 5.11 (s, 2H, H₂), 6.42 (d, 1H, J 8.3 Hz, H₆), 6.64 (bs, 1H, ArH), 6.80 (d, 1H, J 7.9 Hz, ArH), 6.94 (m, 2H, ArH), 7.12 (m, 1H, ArH), 7.26, 7.70 (each bs, 1H, OH).

10

Deprotection Reactions**Example 49*****cis*- and *trans*-Tetrahydrodaidzein**

15 Imidazole (0.2 g) was added to a suspension of 4',7-diacetoxytetrahydrodaidzein (0.10 g, 0.3 mmol) in absolute ethanol (4.0 ml) and the mixture refluxed for 45 min under argon. The solution was concentrated under reduced pressure and distilled water (10 ml) was added. The mixture was left overnight in the fridge and the crystalline product was filtered to yield *cis*- and *trans*-tetrahydrodaidzein (0.06 g, 80%).

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Example 50***trans*-Tetrahydrodaidzein (*trans*-4',7-Dihydroxyisoflavan-4-ol)**

Trans-4',7-dihydroxyisoflavan-4-ol was prepared from *trans*-4',7-dihydroxyisoflavan-4-ol and imidazole in ethanol as described for *cis*- and *trans*-tetrahydrodaidzein. ¹H NMR (d₆-
25 acetone): δ 2.99 (ddd, 1H, J 3.4 Hz, 6.8 Hz, 10.6 Hz, H₃), 4.13 (dd, 1H, J 7.0 Hz, 10.9 Hz, H₂); 4.24 (dd, 1H, J 3.8 Hz, 11.3 Hz, H₂), 4.70 (d, 1H, J 6.4 Hz, H₄), 6.20 (d, 1H, J 2.6 Hz, H₈), 6.38 (dd, 1H, J 2.3 Hz, 8.3 Hz, H₆), 6.71 (d, 2H, J 8.7 Hz, ArH), 7.04 (d, 2H, J 8.7 Hz, ArH), 7.18 (d, 1H, J 8.3 Hz, H₅).

30 Example 51***cis*- and *trans*-7-Hydroxy-4'-methoxyisoflavan-4-ol**

Imidazole (0.4 g) was added to a suspension of 7-acetoxy-4'-methoxyisoflavan-4-ol (0.20 g, 0.6 mmol) in absolute ethanol (8.0 ml) and the mixture refluxed for 45 minutes under argon. The solution was concentrated under reduced pressure and distilled water (10 ml) was added. The mixture was left overnight in the fridge and the crystalline product was filtered 5 to yield *cis*- and *trans*-7-hydroxy-4'-methoxyisoflavan-4-ol (0.16g, 79%).

Example 52

cis- and *trans*-7-Hydroxyisoflavan-4-ol

7-hydroxyisoflavan-4-ol was prepared from 7-acetoxyisoflavan-4-ol (0.14g, 0.5 mmol) and 10 Imidazole (0.17g) in ethanol (3.0 ml) as described for *cis*- and *trans*-tetrahydrodaidzein.

For *trans*-7-hydroxyisoflavan-4-ol; ^1H NMR (d_6 -acetone): δ 3.08 (m, 1H, H3), 4.00 (t, 1H, J 10.2 Hz, H2); 4.30 (m, 1H, H2), 4.81 (d, 1H, J 7.2 Hz, H4), 6.25-6.43 (m, ArH), 6.89 (d, J 8.3 Hz, ArH), 7.07 (d, J 8.3 Hz, ArH), 7.22-7.64 (m, ArH).

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For *cis*-7-acetoxyisoflavan-4-ol; ^1H NMR (d_6 -acetone): δ 3.20 (m, 1H, H3), 4.36 (m, 1H, H2); 4.57 (dd, 1H, J 10.2 Hz, 12.0 Hz, H2), 4.68 (bs, 1H, H4), 6.25-6.43 (m, ArH), 6.89 (d, J 8.3 Hz, ArH), 7.07 (d, J 8.3 Hz, ArH), 7.22-7.64 (m, ArH).

20 Example 53

cis- and *trans*-4',7-Dihydroxy-8-methylisoflavan-4-ol

4',7-Dihydroxy-8-methylisoflavan-4-ol was prepared from 4',7-diacetoxy-8-methylisoflavan-4-ol (0.4g, 1.1 mmol) and imidazole (1.0g) in ethanol (7.0 ml) as described for *cis*- and *trans*-tetrahydrodaidzein.

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For *trans*-4',7-dihydroxy-8-methylisoflavan-4-ol; ^1H NMR (d_6 -acetone): δ 1.98 (s, 3H, CH_3), 2.98 (ddd, 1H, J 3.8 Hz, 10.9 Hz, 12.0 Hz, H3), 4.18 (m, 1H, H2); 4.27 (m, 1H, H2), 4.75 (d, 1H, J 6.4 Hz, H4), 6.42 (m, ArH), 6.75 (m, ArH), 7.05-7.19 (m, ArH), 7.66 (bs, OH).

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For *cis*-4',7-dihydroxy-8-methylisoflavan-4-ol; ^1H NMR (d_6 -acetone): δ 1.99 (s, 3H, CH_3), 3.01 (dt, 1H, J 3.4 Hz, 12.0 Hz, H3), 4.31 (m, 1H, H2); 4.52 (dd, 1H, J 10.2 Hz, 12.0 Hz, H2), 4.60 (bs, 1H, H4), 6.42 (m, ArH), 6.75 (m, ArH), 7.05-7.19 (m, ArH), 7.66 (bs, OH).

5 Example 54

trans-7-Hydroxy-4'-methoxy-8-methylisoflavan-4-ol

trans-7-Hydroxy-4'-methoxy-8-methylisoflavan-4-ol was prepared from *trans*-7-acetoxy-4'-methoxy-8-methylisoflavan-4-ol (0.23g, 0.7 mmol) and imidazole (0.28g) in ethanol (2.1 ml) as described for *cis*- and *trans*-tetrahydrodaidzein. m.p. 162°C. Mass spectrum: 285 M, 10 5%); 268 (10); 151 (20); 135 (20); 134 (100); 119 (20). ^1H NMR (d_6 -acetone): δ 1.97 (s, 3H, CH_3), 3.00 (ddd, 1H, J 3.4 Hz, 7.2 Hz, 10.2 Hz, H3), 3.72 (s, 3H, OMe), 4.20 (dd, 1H, J 7.5 Hz, 10.9 Hz, H2); 4.27 (m, 1H, H2), 4.73 (d, 1H, J 6.8 Hz, H4), 6.45 (d, 1H, J 8.3 Hz, H6), 6.85 (d, 2H, J 8.6 Hz, ArH), 7.10 (d, 1H, J 8.7 Hz, H5), 7.18 (d, 2H, J 8.6 Hz, ArH).

15 Hydrogenation Reactions:— Isoflavone \rightarrow *cis*-Isoflavan-4-ol

Example 55

cis-4',7-Diacetoxyisoflavan-4-ol

Platinum(IV)oxide (Adam's catalyst) (0.05g) was added to a solution of of 4',7-20 diacetoxyisoflavanone (0.25g, 0.7 mmol) in ethyl acetate (40 ml) and the mixture was stirred at room temperature under a hydrogen atmosphere for 55h. The catalyst was removed by filtration through Celite and the filtrate was evaporated *in vacuo* to yield predominantly the *cis*-4',7-diacetoxyisoflavan-4-ol.

25 For *cis*-4',7-diacetoxyisoflavan-4-ol; ^1H NMR (CDCl_3): δ 2.28 (s, 3H, OCOCH_3), 2.29 (s, 3H, OCOCH_3), 3.30 (dt, 1H, J 3.4 Hz, J 11.8 Hz, H3), 4.31 (ddd, 1H, J 1.4 Hz, 3.6 Hz, 10.5 Hz, H2); 4.56 (dd, 1H, J 10.5 Hz, 11.8 Hz, H2), 4.75 (dd, 1H, J 1.3 Hz, 3.2 Hz, H4), 6.66 (dd, 1H, J 2.3 Hz, 8.7 Hz, H6), 6.69 (d, 1H, J 2.3 Hz, H8), 7.08 (d, 2H, J 8.6 Hz, ArH), 7.26 (d, 1H, 8.4 Hz, H5), 7.29 (d, 2H, J 8.6 Hz, ArH). ^{13}C NMR (CDCl_3): δ 20.98 (OCOCH_3), 30 43.52 (C3), 64.10 (C2), 66.46 (C4), 110.08 (C6), 114.09 (C8), 121.82, 129.40 (ArCH), 131.10 (C5).

Hydrogenation Reactions:— Isoflavone → Isoflavan-4-one**Example 56****4',7-Diacetoxydihydrodaidzein (4',7-Diacetoxyisoflavan-4-one)**

5 Palladium-on-charcoal (5%, 0.02g) was added to a solution of 4',7-diacetoxidaidzein (0.50g, 1.5 mmol) in ethyl acetate (80 ml) and the mixture was stirred at room temperature under a hydrogen atmosphere for 72h. The catalyst was removed by filtration through Celite and the resulting filtrate was evaporated *in vacuo*. The residue was recrystallised from ethanol to yield 4',7-diacetoxydihydrodaidzein (0.40g, 80%) as colourless plates. ¹H NMR (CDCl₃):
10 δ 2.29 (s, 3H, OCOCH₃), 2.23 (s, 3H, OCOCH₃), 3.98 (dd, 1H, J 6.2 Hz, 8.2 Hz, H3), 4.69 (m, 2H, H2), 6.78-6.82 (m, 2H, ArH), 7.08 (d, 2H, J 9.2 Hz, ArH), 7.30 (d, 2H, J 8.2 Hz, ArH), 7.98 (d, 1H, J 9.2 Hz H5).

Hydrogenation Reactions:— Isoflavan-3-ene → Isoflavan

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Example 57**O,O-Diacetyllequol**

Palladium-on-charcoal (5%, 0.02g) was added to a solution of 4',7-diacetoxyisoflav-3-ene (0.20g, 0.06 ml) in ethyl acetate (60 ml) and the mixture was stirred at room temperature
20 under a hydrogen atmosphere for 24h. The catalyst was removed by filtration through Celite and the resulting filtrate was evaporated *in vacuo*. The residue was recrystallised from dichloromethane/light petroleum to yield O,O-diacetyllequol (0.15g, 75%). ¹H NMR (CDCl₃): δ 2.29 (s, 3H, OCOCH₃), 2.31 (s, 3H, OCOCH₃), 3.00 (d, 2H, J 8.3 Hz, H4), 3.25 (m, 1H, H3), 4.00 (t, 1H, H2), 4.34 (dd, 1H, J 3.4 Hz, 10.9 Hz, H2), 6.61 (d, J 7.5 Hz, 1H, ArH), 6.60 (s, 1H, ArH), 7.06 (bd, 3H, J 8.3 Hz, ArH), 7.24 (d, 3H, J 8.3 Hz, ArH).
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Deprotection Reactions**30 Example 58****Dihydrodaidzein (4',7-Dihydroxyisoflavan-4-one)**

Imidazole (0.63g) was added to a suspension of 4',7-diacetoxydihydrodaidzein (0.26g, 0.08 mmol) in absolute ethanol (5.0 ml) and the mixture was refluxed for 45 min under argon.

The solution was concentrated under reduced pressure and distilled water (10 ml) was added to the residue. The mixture was left overnight in the fridge and the resulting precipitate was filtered. The crude product was recrystallised from ethyl acetate/dichloromethane to yield 4',7-diacetoxylidihydrodaidzein (0.14g, 71%) as a white powder. ¹H NMR (d₆-acetone): δ 3.83 (t, 1H, J 7.2 Hz, H3), 4.60 (d, 2H, J 6.2 Hz, H2), 6.39 (d, 1H, J 2.0 Hz, H8), 6.55 (dd, 1H, J 8.2, J 2.0 Hz, ArH), 6.80 (d, 2H, J 8.2 Hz, ArH), 7.10 (d, 1H, J 8.2 Hz, ArH), 7.74 (d, 1H, J 8.2 Hz, H5).

Example 59

10 Equol (4',7-Dihydroxyisoflavan)

Imidazole 0.5g) was added to a suspension of O,O-diacetylsquol (0.15g, 0.08 mmol) in absolute ethanol (5.0 ml) and the mixture was refluxed for 45 min under argon. The solution was concentrated under reduced pressure and distilled water (10 ml) was added to the residue. The mixture was left overnight in the fridge and the resulting product was 15 filtered to yield equol (0.09g, 80%) as a white powder. ¹H NMR (d₆-DMSO): δ 2.70 (d, 2H, J 9.2 Hz, H4), 2.92 (m, 1H, H3), 3.73 (t, 1H, J 10.3 Hz, H2), 4.06 (dd, 1H, J 3.0 Hz, 11.2 Hz, H2), 6.16 (bs, 1H, ArH), 6.21 (bd, J 8.2 Hz, 1H, ArH), 6.63 (d, 2H, J 8.2 Hz, ArH), 6.69 (d, 1H, J 8.2 Hz, ArH), 6.87 (d, 2H, J 8.2 Hz, ArH)

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Those skilled in the art will appreciate that the invention described herein is susceptible to variations and modifications other than those specifically described. It is to be understood that the invention includes all such variations and modifications. The inventions also includes all of the steps, features, compositions and compounds referred to or indicated in 25 the specification, individually or collectively, and any and all combinations of any two or more of said steps or features.

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